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ABSTRACT

Visualization as a factor of intelligence includes the mental manipulation of spatial configurations and has been associated with spatial abilities, creative thinking, and conceptual problem solving. There are numerous reports of scientists and mathematicians using visualization to anticipate transformation of the external world. Artists and designers use visualization to record concepts leading to the development of new ideas and as a visual aid for continuing idea generation. Graphic imagery is used to communicate information as well as to generate concepts. Models and diagrams are two methods of representing information and may aid in developing theories related to structure or relationships in three-dimensional space. Also in this category are information graphics, computer simulations, and imaging from medical technologies. These images not only convey basic information but allow the viewer to see relationships or patterns that would not otherwise be apparent. Courses have been developed to enhance mental and graphic visualization skills. For the most part, however, there is a lack of emphasis on visual skill development. The shift from print to electronic media will increase the need to educate the next generation for the use and interpretation of visual images. Includes five illustrations. (Contains 18 references.) (KRN)

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Visualization in Science and the Arts

by
Susan King Roth

To *visualize* is "to recall or form mental images or pictures (Random House, 1991)." The term *visualization* is employed in a number of ways. As popularized in the media it refers to the act of visualizing success in sports or other arenas of endeavor. This, however, is *not* the meaning explored here. Visualization as a factor of intelligence includes the mental manipulation of spatial configurations and has been associated with spatial abilities, creative thinking, and conceptual problem solving. The Educational Testing Service, which publishes standardized tests for the assessment of cognitive skills and abilities, defines visualization as "the ability to manipulate or transform the image of spatial patterns into other arrangements (Ekstrom et al., 1976)." The process involves holding the configuration in short-term memory and performing serial operations such as rotation or reflection. It is closely related to problem-solving methods and concept generation in fields as diverse as science, art, and design.

Visualization refers to both an internal process (the formation and manipulation of mental imagery) and an external means of communication (the creation of graphic

imagery). See fig. 1. Graphic imagery such as three-dimensional models may also be used for theory development as well as for communication of concepts.

INTERNAL PROCESS:
Formation and Manipulation
of Mental Imagery
for creative thinking and
problem-solving

EXTERNAL
COMMUNICATION:
Graphic Imagery
including models, charts,
computer simulations

Fig. 1

Because mental imagery may be analogous to real-life phenomena the manipulation of mental images can assist in the process of problem-solving related to these phenomena. According to Antonietti: "Mental images may provide a simplified representation of the content of the cognitive task...Moreover, images permit representation of objects and events in an analogue format, so that it is possible

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mentally to anticipate transformation of the external world (1991)." There are numerous reports of visualization being used in this way by scientists and mathematicians, for the solution of problems that would not yield to attack by more analytical methods. Shepard (1978) cites several accounts of such methods used by prominent individuals throughout history in the development of significant contributions to science and mathematics.

For example, Albert Einstein used visualization to arrive at the theory of relativity and was able to "see" the logic of the theory through the manipulation of analog images. Lecturing at the Prussian Academy of Sciences in 1921 he explained the concept of spherical space through a description of visual imagery: "...by using as a crutch the practice in thinking and visualization which Euclidean geometry gives us, we have acquired a mental picture of spherical geometry. We may without difficulty impart more depth and vigour to these ideas by carrying out special imaginary constructions (French, 1979)." Quoted in Shepard, Einstein said: "There is no logical way to the discovery of these elemental laws. There is only the way of intuition, which is helped by a feeling for the order lying behind the appearance."

Einstein's predecessor, Michael Faraday, had an aversion to writing and lacked an education in mathematics. Yet he was able to visualize "lines of force" curving in space around magnets and electric currents, thus originating the conception of magnetic and electric fields. Jacques Hadamard, a noted mathematician, wrote: "I insist that words are totally absent from my mind when I really think." Shepard also recounts the story of James Watt, who invented the steam engine, as he worked for two years to make the engine feasible, finally coming upon a solution during an afternoon walk when the engine

and its parts and relationships appeared completely resolved in his mind.

And finally, the German chemist Kekulé discovered the molecular structure of benzene, revolutionizing organic chemistry, through visualization. "Seeing" atoms playing before his eyes while dozing, they suddenly formed a long chain which twisted and turned like a snake. Kekulé writes: "But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightning, I awoke (Adams, 1979)." He realized that the structure of organic compounds such as benzene was a closed ring. Many other instances have been recorded in which visualization was used to arrive at a solution to scientific or mathematical problems through the manipulation of mental images.

It is perhaps less surprising that artists and designers make use of visualization to facilitate the creative process. Although the products of design and art are different – design involves the development of images and objects with utilitarian as well as aesthetic value – the process of generating and expressing ideas is similar. Because of longterm experience with visual form, it is likely that artists and designers have a highly-developed ability to visualize. A study conducted by R. Davies and R.J. Talbot (1987) into the lives of 35 Royal Designers for Industry in the United Kingdom revealed in fact that they "often described a facility in using mental imagery, for example as a multi-sensory and dynamic, mental sketch pad; using mental rotation and scanning images..." Lord states: "The ability to mentally juxtapose, manipulate, and rotate an object and to create structures in the mind from written or verbal directions has been shown to be a tremendous benefit in many of today's vocations...artists, architects, engineers and craftsmen scored

consistently higher on tests for visuo-spatial accuracy than most other trades... (1987)."

The sculptor Henry Moore wrote that the sculptor "gets the solid shape, as it were, inside his head...He mentally visualizes a complex form from all round itself: he knows while he looks at one side what the other side is like...(Ghiselin, 1952)." Leonardo da Vinci made the observation that creative processes were prompted by his examination of stains on the wall "you may discover a resemblance to various landscapes, beautified with mountains, rivers, rocks, trees...or again you may see battles and figures in action, or strange faces and costumes, and an endless variety of objects which could reduce to complete and well-drawn forms (Da Vinci)." His notebooks were full of sketches and drawings of objects and scenes drawn from observation and from the imagination (see fig. 2).

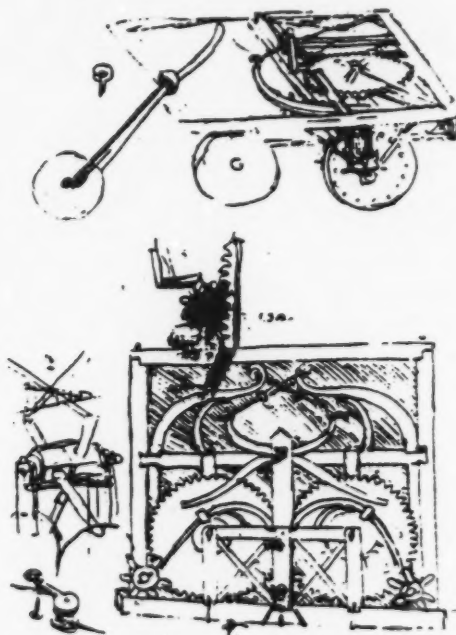


Fig.2. Leonardo's horseless wagon. *The Inventions of Leonardo da Vinci*. Macmillan.

Many artists and designers work from a rough sketch to more finished sketch and then on to models, prototypes, or the final product of the process. Used in this way the graphic representation of mental images, or conceptual sketching, acts as a visual notation system. The quick sketches which characterize the beginning stages of the design process are made not for communication with others but as a way of recording concepts leading to the development of new ideas, a visual aid for continuing idea generation. The concept is often displayed in several views, or important details may be enlarged and examined visually (see fig.3).

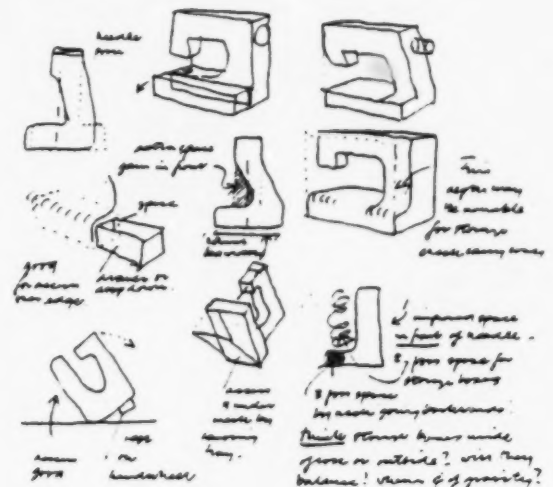


Fig. 3. Concept sketches for design of a sewing machine. Pentagram. *Living By Design*.

Several books have been written on this process; one is *Rapid Viz* by Hanks and Belliston (1981), another is *Experiences in Visual Thinking* by Robert McKim (1972). Courses have been developed at various universities such as Stanford and The Ohio State University to enhance mental and graphic visualization skills for engineering and design students.

For the most part, though, there is a lack of emphasis on visual skill development in the educational system. Dr. Howard Gardner of Harvard University has argued that "schools ignore valuable skills like the spatial abilities of an architect or an engineer (Fiske, 1989)." How many people have well-developed drawing abilities or use visual notation as often as they use written notation? The ability to communicate through graphic images often atrophies after the elementary education level, where it is accorded some degree of importance.

Graphic imagery is used for the communication of information as well as for the generation of concepts. Models and diagrams are two methods of representing information and may aid in developing theories related to structure or relationships in three-dimensional space. The model of the DNA double helix constructed by Nobel prize-winners Watson and Crick was built in order to visualize a complex structure through direct interaction with the model; it also served to illustrate the proposed structure to others. Linus Pauling's sketch-model of the protein molecule (shown unfolded) is another example (Fig. 4).

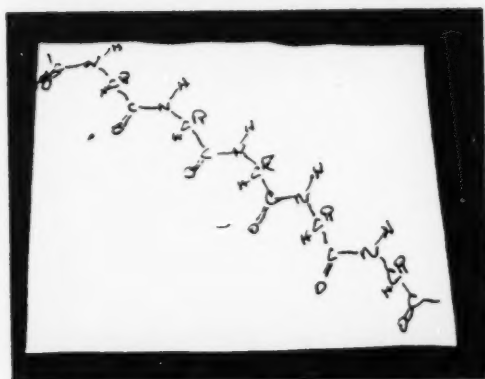


Fig. 4. Paper sketch-model of protein molecule by Linus Pauling. (Judson, H. *The Search for Solutions*. New York: Holt, Rinehart, and Winston, 1980.)

Also in this category are information graphics (charts, maps, graphs, illustrations, etc.), computer simulations, and imaging from medical technologies such as X-rays and MRI scans. In each case the image not only conveys basic information, but also allows the viewer to see relationships or patterns that would not otherwise be apparent. As an example, John Snow's map of London (Fig. 5) is a "spot map" showing the worst areas of infection with asiatic cholera, indicating an apparent connection between the Broad Street Pump and spread of the disease.



Fig. 5. J. Snow's map of London with areas of infection with the cholera epidemic marked. (J. Fox, C. Hall, and L. Elveback. *Epidemiology*. New York: Macmillan, 1970.)

Aids to visual perception such as the microscope, the telescope, and the satellite camera have opened up new worlds for visual exploration. The visual evidence gathered from these devices has prompted the development of theory and brought us closer to understanding the structure of the universe and its contents.

New technologies in the area of computer graphics and simulations

communicate information not available through previous methods of visualization. Medical imaging makes possible a look into the living human body, illuminating areas formerly hidden from view. Designed products are modelled and manipulated on a computer, which can be connected to machines that produce three-dimensional models of the computer image. The power of computer simulations and modelling represents other ways of both knowing and communicating, and the current shift from print to electronic media will increase the need to educate the next generation for the effective use and interpretation of visual images.

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